PB87-103032

Full Scale Plume Study
A Summary of Data
Collected and Phenomena Observed

Environmental Research and Technology, Inc.
Concord, MA

Prepared for

Environmental Protection Agency
Research Triangle Park, NC

Sep 86

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. PB87-103032
EPA/600/D-86/219		

4. TITLE AND SUBTITLE	5. REPORT DATE
THE FULL SCALE PLUME STUDY: A Summary of Data Collected and Phenomena Observed	September 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
T. Lavery, G. Holzworth, F. Schiermeier, W. Snyder, L. Truppi, B. Greene, & B. Egan	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Environmental Research & Technology, Inc. 696 Virginia Road Concord, MA 01742	CDTA1D/09-0566 (FY-86)
	11. CONTRACT/GRANT NO.
	68-02-3421
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Atmospheric Sciences Research Laboratory - RTP,NC Office of Research and Development U. S. Environmental Protection Agency Research Triangle Park, NC 27711	14. SPONSORING AGENCY CODE EPA/600/09
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

This paper briefly describes the field tracer studies that were conducted in support of EPA's Complex Terrain Model Development project. A more detailed description is given of the last field study, conducted from the Tracy Power Plant near Reno, Nevada. During 14 experiment periods, 128 hours of dual-tracer samples were collected at up to 100 locations. These concentration measurements were supported by conventional meteorological information as well as information from lidars and monostatic and doppler acoustic sounders. Finally, the paper describes some typical but complex flow patterns that occurred during stable conditions in the irregular terrain of the study area.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	12
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/600/D-86/219
September 1986

THE FULL SCALE PLUME STUDY: A SUMMARY OF DATA COLLECTED AND PHENOMENA OBSERVED

Thomas F. Lavery

Sigma Research Corporation
Lexington, Massachusetts 02173

George C. Holzworth
Francis A. Schiermeier
William H. Synder
Lawrence E. Truppi

U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Benjamin R. Greene
Bruce A. Egan

ERT, Inc.
Concord, Massachusetts 01742

1. INTRODUCTION

The Complex Terrain Model Development (CTMD) project is being sponsored by the U.S. Environmental Protection Agency (EPA) to develop atmospheric dispersion models to simulate air pollutant concentrations in complex terrain that result from emission from large sources. The emphasis of the project is to develop models with known accuracy and limitations for simulating 1-hour concentrations in high terrain during stable conditions. To support the model development activities, four major tracer and flow visualization field experiments have been conducted since September 1980. The resulting data bases and data from towing tank and wind

tunnel studies, conducted at the EPA Fluid Modeling Facility, and our understanding of the physical processes have been used to develop the Complex Terrain Dispersion Model (CTDM).

The rationale for the field experiments was to gain an understanding of dispersion at a relatively simple site and proceed to sites with more complicated terrain. Each field study was designed and directed by the model developers. The components common to each experiment included: the release, sampling and analysis of two tracer gases (SF_6 and CF_3Br); the release of oil-fog and the documentation of its behavior by lidar measurements and photographs, and extensive fixed and remote meteorological measurements. The SF_6 and oil-fog were usually released coincidentally to obtain quantitative ground-level concentrations and, at the same time, a visualization of plume dispersion.

The first field experiment, Small Hill Impaction Study No. 1 (SHIS #1), was conducted during the fall of 1980 at Cinder Cone Butte (CCB), Idaho. CCB is a roughly axisymmetric, isolated 100-m tall hill located in the broad Snake River Basin near Boise, Idaho. SHIS #2 was performed during October 1982 at the Hogback Ridge (HBR) near Farmington, New Mexico. HBR is a long, 90-m tall ridge located on the Colorado Plateau near the western slopes of the San Juan Mountains. At these sites the tracer gases were released from mobile cranes or a tower.

The third and fourth field experiments were conducted at the Tracy Power Plant (TPP) located next to the Truckee River east of Reno, Nevada. The third experiment, performed in November 1983, was undertaken as feasibility and design study for the Full Scale Plume Study (FSPS). It was co-sponsored by the Electric Power Research Institute (EPRI). The November experiment not only demonstrated the feasibility of conducting the FSPS at the TPP, but with the expanded scope made possible by EPRI's participation, it also produced a data

base that itself is useful for modeling purposes. The FSPS was performed at Tracy in August 1984.

2. THE FSPS AND ITS RESULTANT DATA BASE

The TPP was selected as the site of the FSPS after an extensive survey of all power plants in the western United States located in settings that could qualify as complex terrain. The Tracy site is in the Truckee River valley about 17 miles east of Reno. The plant has three units, but only Unit 3 with 120-MW capacity and a 300-foot (91.4 m) stack is operating. Geographically the site has merit in that stable flows from the west are fairly common at night. The Sierra Nevada to the west of Reno and the Pah Rah Mountains to the east define the Truckee Meadows basin in which the Reno-Sparks urban area lies. The Truckee River has cut a canyon through the Pah Rah range and drops approximately 200 feet from Sparks to Tracy. Large-scale downslope winds off the Sierra at night flow through the canyon and reinforce the drainage down the river.

At the plant site (Figure 1), the valley broadens to the north towards the Pah Rah Mountains. To the south, Clark Mountain rises almost 3,000 feet (910 m) above the stack base in seven km. At about 4.5 km east of the plant, the river swings sharply north through a narrow gorge between two large obstacles, "Beacon Hill" (5232 ft. MSL, or about 300 m above stack base) to the west of the gorge and "Target Mountain" (5764 ft. MSL or about 460 m above stack base) to the east. These two terrain elements were the principal "target" areas in the anticipated westerly winds.

The components of the FSPS were basically the same as those used in the Small Hill Impaction Studies. Two tracers, SF6 and CF_3Br, were released simultaneously from two different locations to give twice the dispersion information at a small increase in cost. A "smoke" plume was produced by evaporation of corvus oil in a small jet

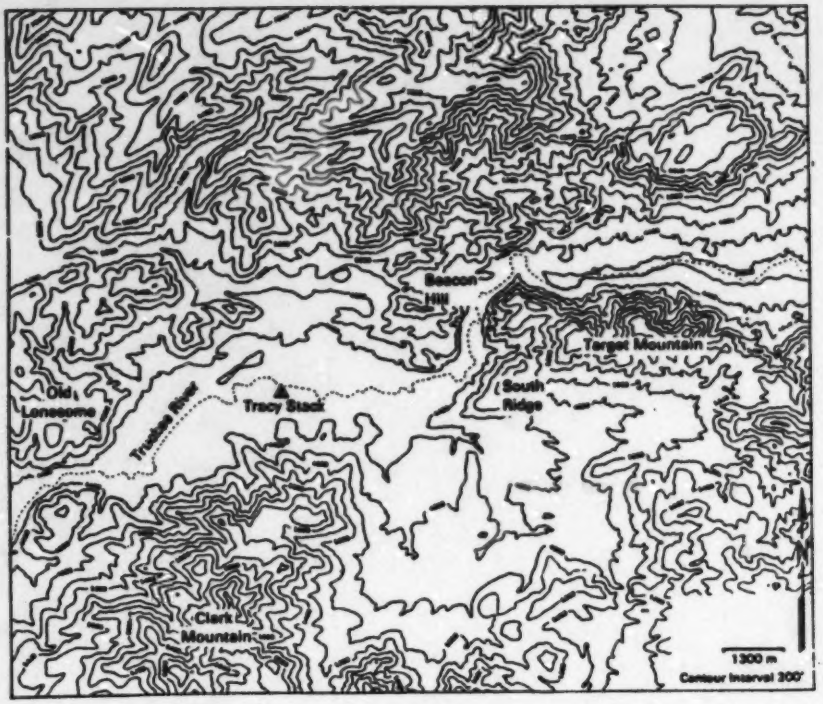

Figure 1: Plant site

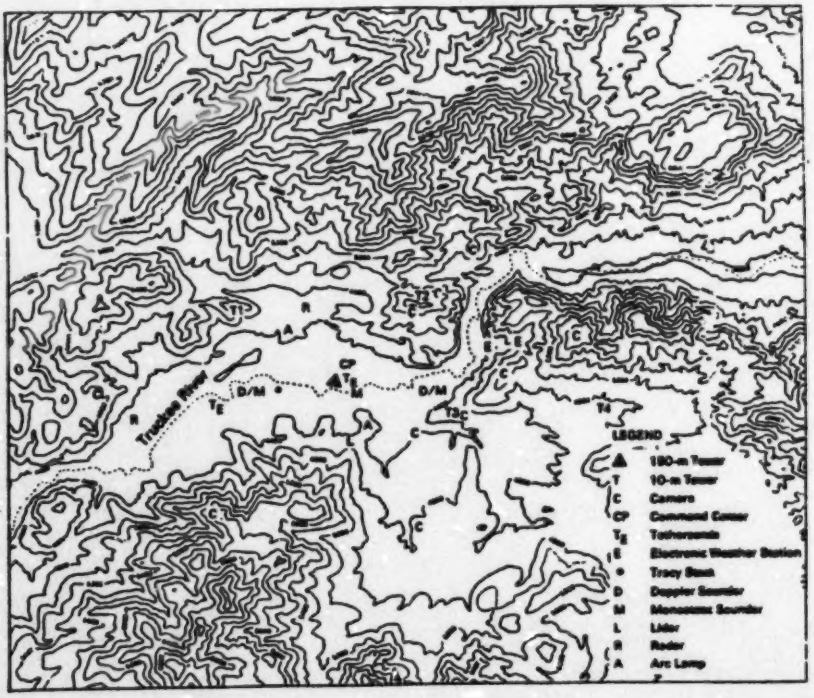

Figure 2: FSPS Field Experiment Layout.

aircraft engine exhausted into the side of the duct leading from the power boiler to the stack. SF_6 was injected into the same gas stream through a sampling port just upstream of the breaching into the flue. CF_3Br was released from one of three heights on the 150-m meteorological tower.

One-hour samples of ground-level tracer concentrations were obtained at more than 100 locations in two-liter Tedlar bags. Three additional samplers were mounted on the tall tower. Analysis of tracer concentrations was done by gas chromatography with electron-capture detection.

Ground-based lidar made vertical transects through the oil-fog plume, usually at five distances downwind, to measure the location and dimensions of the plume and its proximity to terrain.

The ALPHA-1 airborne lidar tracked the plume to greater distances. Color photographs of the plume were taken routinely every five minutes from five locations, and video-tapes were made during daylight hours. Two carbon-arc lamps panned along the plume for illumination when natural light was insufficient. Scientist-observers took additional color slides and, after dawn, 8-mm time-lapse movies as well.

Meteorological measurements were made from the 150-m tower, four 10-m towers, two electronic weather stations, two tethersondes, and one monostratic and two doppler sodars. Two radar-tracking balloon sounding systems were also used. Figure 2 shows the locations of the various meteorological sensors, the lidar, and the Command Center.

The FSPS comprised 14 tests or experiments and a total of 128 hours of data collection. Table 1 lists the dates and duration of the 14 experiments. Experiment hours encompassed a variety of meteorological conditions ranging from very stable with very

TABLE 1. FSPS EXPERIMENT HOURS OF TRACER RELEASE AND CONCENTRATIONS

Experiment	Date (Aug 84)	Time (PDT)	Release			Concentrations	
			Oil-Fog	SF_6	CF_3Br	SF_6	CF_3Br
1	6	03-07	4	4	4	4	
2	7	03-07	4	4	4	4	4
3	9-10	20-06	8	10	10	10	10
4	10-11	20-06	10	10	10	10	10
5	11-12	20-06	8	10	9	10	10
6	15-16	22-08	10	10	10	10	10
7	16-17	22-08	10	10	10	10	10
8	17-18	22-08	5	11	11	10	10
9	20-21	22-08	10	10	10	10	10
10	21-22	23-09	7	10	10	10	10
11	22-23	23-09	10	10	10	10	10
12	25	00-10	10	10	10	10	10
13	26	00-10	10	10	10	10	10
14	27	00-10	9	10	10	10	10
Total			115	129	128	128	128

light winds to morning inversion breakup and fumigation. On several evenings early in an experiment, strong winds from the west produced near-neutral flow in the valley. Prolonged periods of stable plume impaction on the targeted elevations to the east frequently occurred.

The tracer concentration database contains 11,609 concentrations for either tracer gas. Most of the meteorological instrumentation performed well and data capture is good. ALPHA-1 gave airborne lidar coverage during 75 experiment hours. WPL's lidar operated reliably except for a few brief periods. The photography contractor submitted an archive of more than 11,700 35-mm color slides and 14 VHS videotapes.

After an assessment of the results of all QA activities and the subsequent refinement of the FSPS data base (Greene, 1986), a Modelers' Data Archive (MDA) was prepared for use in the evaluation (DiCristofaro and Egan, 1986) of CTDM and other models. The MDA contains observed 1-hour average concentration data, tracer release information, and meteorological variables and derived parameters estimated at plume height for each of the hours during the FSPS in which either SF_6 or CF_3Br tracer gas was released. The SF_6 MDA is limited to the 84 hours for which lidar data are available. The "effective" height of the SF_6 and oil-fog plume was estimated from lidar measurements of the centroid height of the plume.

3. FSPS Data Interpretation

The FSPS data base is currently being analyzed for two fundamental purposes: (1) to refine and evaluate CTDM and the individual model components, and (2) to gain an understanding of the stable boundary layer (SBL) and physical phenomena that control dispersion in complex terrain. The progress on the development of CTDM has been described by Strimaitis et al (1986), Strimaitis and Snyder

(1986) and DiCristofaro and Egan (1986). This paper summarizes the current work on the characteristics of the SBL at Tracy and the behavior of the plumes released from the Tracy stack.

An overview (Neff, 1985) of the entire FSPS might be as follows: First the period before midnight is windy with weak stability and deep mixing, often to 400 m. The period from midnight to 0800 is characterized by increasing stability. The strength of the inversion and the winds determine whether waves or instabilities dominate the smaller scale motions. Under more stable conditions, several wind maxima are present while under stronger wind conditions, a single elevated jet will form. After 0800, the elevated inversion descends and meets the growing convective layer, usually around 1000. This interpretation follows to a large extent from the analysis of Neff and King (1985).

An examination of the sodar facsimile records, sonic and other meteorological data, lidar measurements and photographs suggest that the SBL can be generally described by four categories:

a. Strong layering: In this category, characteristics of stronger stability and weaker winds, isolated echo layers are interspersed with laminar regions. Short period internal waves are often present, suggesting that the dynamics of the inversion layer are dominated by static stability rather than shear. Vertical diffusion is small relative to lateral diffusion. In these cases, the behavior of the plume depends on the particular layer in which it is embedded. An important feature evident in the data base is the patchiness of the turbulence and the evidence for measuring layers. The highest ground-level SF_6 concentration (GLC) was obtained during a strong layering event.

b. Elevated Jet: In these cases, a wind maximum occurs between 150 and 300 m. Above this height, an elevated echo layer is preesnt. Below the jet, shear arising from surface friction produces a ground-based mixing layer. Longer period oscillations are sometimes superimposed on these structures.

In these cases, persistent echo layers are sometimes observed as in Category a. However, the layers here are dominated by dynamical instability rather than by short period internal waves, indicating that shearing motions dominate the dynamics rather than static stability. In such cases, greater vertical diffusion of the plume was observed.

c. Complex drainage flows: These cases reflect a mixture of processes, primarily layering combined with occasional deeper mixing due to fluctuations in the mean wind and shear. In these situations, plume diffusion is erratic because of the mixture of wave motions and dynamical instability.

d. Simple boundary/inversion layers: This category includes cases when the effect of shear-induced mixing combined with surface cooling to produce a single mixing layer based at the surface. A plume in this surface layer is well mixed in the vertical.

During these stable conditions plume behavior and the locations and magnitude of the GLC are controlled by the height of the plume relative to the heights of the elevated stable layer and wind maxima. A plume trapped in an elevated layer will be limited vertically by the depth of the layer and its impingement area will be determined by where the elevated layer interacts with the terrain. Although the highest GLC were observed during windward impingement events, high concentrations also occurred during events when the SF_6 and, especially, CF_3Br plumes were channelled down the Truckee River into the gorge between Beacon Hill and Target Mountain. Other events that are important, relative to plume dispersion,

that were observed during the FSPS include: fumigation (during the growth of the early morning convective layer and during flow reversals); aerodynamic downwash (in the lee of the Tracy plant and in the lee of the hills and mountains); and other wave-induced events.

Again, the hightest GLC was measured on Beacon Hill during strong layering event. Several other high GLC were observed during very stable conditions. DiCristofaro et al (1986) showed that the higher GLC occurred when the height of plume was near the height of the critical dividing streamline (H_c). In fact, the H_c - concept is central to CTDM. Other important concepts include plume rise (see Paine et al, 1986), initial plume growth (from internal plume buoyancy), vertical and horizontal plume diffusion (from atmospheric turbulence), and the effects of terrain on dispersion. These concepts are currently being analyzed using the FSPS data base.

4. REFERENCES

DiCristofaro, D.C. and B.A. Egan, 1986. A Comparison of Complex Terrain Models Using the Full Scale Plume (FSPS) Database: COMPLEX I, RTDM, and CTDM, Proceedings of the Fifth Joint Conference on Applications of Air Pollution Meteorology, AMS, Boston, MA.

DiCristofaro, D.C., D.G. Strimaitis, B.R. Greene, R.J. Yamartino, A. Venkatram, D.A. Godden, T.F. Lavery, and B.A. Egan, 1986. EPA Complex Terrain Model Development Program: Fifth Milestone Report - 1984. EPA/600/3-84/110, U.S. EPA, Research Triangle Park, NC.

Greene, B.R., 1986. Complex Terrain Model Development: Quality Assurance Project Report for the Full Scale Plume Study, ERT Document No. P-B876-725, ERT, Concord, MA.

Neff, W.D., 1985. Overview of Sodar Data from

FSPS, August 1984. NOAA WPL, Boulder, CO.

Neff, W.D. and C.W. King, 1985. Studies of Complex Terrain Flows Using Acoustic Remote Sensors, ASCOT 85-1, NOAA, WPL, Boulder, CO.

Strimaitis, D.G., D.C. DiCristofaro, and T.F. Lavery, 1986. The Complex Terrain Dispersion Model. Proceedings of 79th Meeting of APCA. June 22-27, Minneapolis, MN, APCA, Pittsburgh, PA.

Strimaitis, D.G. and W.H. Snyder, 1986. An Evaluation of the Complex Terrain Dispersion Model Against Laboratory Observations: Neutral Flow Over 2-D and 3-D Hills. Proceedings of the Fifth Joint Conference on Applications of Air Pollution Meteorology, AMS, Boston, MA.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.